

Operation of the Westinghouse Fluidized Bed Devolatilizer with a Variety of Coal Feedstocks

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Under Energy Research & Development Administration sponsorship, Westinghouse is conducting a diverse program to develop a low Btu coal gasification, combined cycle electrical power generating process. The total program includes work in gas turbine combustor development, studies of turbine tolerance to erosive and corrosive fuel, gas cleaning and coal gasification process development. As part of the gasification work, Westinghouse is operating a process development unit (PDU) at Waltz Mill, Pennsylvania. It is this aspect of the program that will be discussed.

PROCESS DESCRIPTION

Before we discuss specific test results, a brief introduction to the process is in order. Essentially, the Westinghouse Fluidized Bed Process consists of two reactors (Figure 1). Coal is fed by pneumatic transport from lock hoppers to the devolatilizer-desulfurizer reactor where it is fluidized by hot reducing gases produced in the gasifier-agglomerator reactor. The coal and hot gas are transported at relatively high velocity upward in a draft tube along the reactor centerline. Devolatilized coal or char product is also entrained in the upward flow of solids and gases in the draft tube. This dilution - on the order of 30 to 1 - of fresh coal with char in the entrained bed of the draft tube prevents the fresh coal from sticking together or caking as it is heated through its plastic stage. When the coal leaves the draft tube, it enters a second portion of the fluidized bed where devolatilization is completed and where desulfurization takes place. The latter is achieved by absorption of the hydrogen sulfide with dolomite which is also circulating in the fluidized bed with the char product.

Char from the devolatilizer is continuously drawn from the bed and fed to the gasifier-agglomerator reactor. A portion of the char is combusted with air in the combustor zone at the bottom of the reactor. This zone is operated at a temperature of about 1950°F at which ash particles stick together or agglomerate and become defluidized. Ash is continuously removed from the bottom of the reactor after being cooled with steam. This steam is used to gasify the remainder of the char and to moderate the combustor temperature. The heat produced in the combustor is carried to the gasification zone by circulating solids and fluidizing gases composed essentially of CO, CO₂, H₂, H₂O and N₂. Eventually this gas exits the gasifier and enters the devolatilizer where it provides a heating and fluidizing medium for the bed.

The hot product gases leave the devolatilizer at about 1600°F and 225 psig and go through various stages of cleaning for particulate removal prior to being combusted with air in a gas turbine - steam turbine combined cycle generating plant. Nominally, a 50 T/H coal gasification plant produces sufficient gas for 130 MW of electricity plus the compressed air and steam used in the process. The low Btu gases have a heating value of about 120 Btu/scf.

PDU RESULTS

In August 1976, the initial series of tests of the devolatilizer reactor were completed on the PDU scale of nominally 15 T/D. These tests were conducted with a variety of feedstock materials and conditions and culminated with the "feasibility demonstration" of the system with two highly caking Eastern bituminous coals. These coals

were processed for over 200 hours in the devolatilizer without pretreatment. This was a major accomplishment in coal gasification development because the use of costly and inefficient pretreating operations (usually by surface oxidation) to decake Eastern coals was not necessary.

The devolatilizer test program was comprised of three types of test: plant start-up/shutdown, system sensitivity and feasibility demonstration runs. Essentially the work began with non-caking coal feedstocks, progressed to mildly caking bituminous coal and concluded with highly caking Pittsburgh and Upper Freeport seam coals. This test sequence is summarized in Table I. Coal properties are shown in Table II. Typical char product properties are given in Table III.

The principal product of the devolatilizer reactor is de-caked coal or char. To understand and predict the dynamics of the integrated gasification plant, the operating characteristics of the devolatilization process must be considered. Because the Westinghouse gasifier is a fluidized bed reactor, the effect of devolatilization on the char production rates and on the fluid dynamic properties of the char particles are critical. These properties include char particle size distribution, the fraction of coal feed that becomes char product, and the split of that product between drawoff from the bed and overhead product taken from the gas stream in the particulate removal cyclone.

To study these effects, the geometric weight mean of char samples withdrawn from the bed (this does not include char product which goes overhead with the product gas) expressed as a dimensionless ratio, geometric weight mean of char to geometric weight mean of coal, has been explored as a function of the operating parameters involved.

TABLE I

PDU Devolatilizer Test Program

<u>Type of Test</u>	<u>Type of Feedstock</u>	<u>Name of Feedstock</u>	<u>No. of Hrs. Coal Processed</u>
PDU Shutdown	Lignite Derived Char	Husky Char	17
	Sub-Bituminous-C	Sorensen	13
	High Volatile Bituminous	Minnehaha/Indiana #7	30
System Sensitivity	High Volatile Bituminous	Minnehaha/Indiana #7	191
	Medium Volatile Bituminous	Champion/Pittsburgh	30
Feasibility Demonstration	High Volatile Bituminous	Minnehaha/Indiana #7	131
	Low Volatile Bituminous	Renton/Freeport	96
	Medium Volatile Bituminous	Champion/Pittsburgh	91
TOTAL			599

TABLE II

Coal Raw Materials

Coal Company Mine Seam	Kemmerer Sorensen Adaville	Amax Minnehaha Indiana 7	Consol Montour Pittsburgh	Consol Renton Upper Freeport
Analysis (%)				
Volatiles	36.4	32.1	35.0	35.6
Carbon	41.0	43.3	49.0	53.8
Moisture	19.9	16.2	6.5	1.7
Ash	2.7	8.4	9.5	8.9
Sulfur	0.4	0.5	1.9	1.4
Ash Fusion (Reducing) °F				
I.D.	NA	2170	2270	2510
H=W	NA	2270	2310	2570
H=1/2W	NA	2320	2350	2600
Fluid	2160	2380	2400	2650
Free Swelling Index	0	1-1/2 - 2	7 - 9	8 - 9
Gieseler Plasticity ddm	NA	250	25,000	30,000
Heating Value, Btu/ lb, MAF	13,217	14,250	12,570	13,740
Bulk Density, lb/ft ³	45.0	43.8	43.6	44.6

TABLE III

Char Product Properties

Coal Company Mine Seam	Kemmerer Sorensen Adaville	Amax Minnehaha Indiana #7	Consol Montour Pittsburgh	Consol Renton Upper Freeport
Analysis (%)				
Volatiles	6.2	2.7	2.9	2.7
Carbon	83.1	77.1	76.4	78.0
Moisture	1.7	1.0	0.6	1.5
Ash	9.0	19.2	18.2	16.6
Sulfur	0.3	0.2	1.9	1.2
Free Swelling Index	NA	NA	0	NA
Gieseler Plasticity ddm	NA	NA	No Fluidity	NA
Bulk Density, lb/ft ³	14.7	24.2	29.0	22.0

At this time, the data does not allow sophisticated prediction of reactor behavior; however, empirical correlations of results have been made to identify critical parameters. Essentially, relationships were sought between the diameter ratio and the operating parameters presented in Table IV as first order effects for each parameter and for every combination of paired parameters described in Table IV. For example, the first entry in the table (on the coal feed rate row and coal feed rate column) indicates no correlation was found for the available data for the diameter ratio versus the coal feed rate alone. However, proceeding to the next column, the table indicates a fair correlation for the diameter ratio versus coal feed rate when the reactor freeboard velocity is used to parameterize the data. The general criteria used to judge the extent of the correlation was $\pm 10\%$ scatter for a strong correlation, $\pm 15\%$ scatter for a weak correlation, and no correlation for scatter beyond 15%.

As can be seen from Table IV, the gas velocity through the reactor (Figure 2) and the rank of the coal feedstock (Figure 3) correlate the data. In order to get a more complete picture, the data have been correlated in Figure 4 to include all of the pertinent effects. Several observations can be made from this plot. Due to the narrow temperature spread for the reactor gas, the constant freeboard velocities lines drawn through the data are essentially constant gas input rate lines. Thus, proceeding to the right along a freeboard velocity line indicates the effect due to increasing the coal feed rate. The increasing slope of the three lines drawn indicates greater sensitivity to the coal feed rate as the freeboard velocity and/or rank of the coal are increased. Because the reactor freeboard velocity and the coal rank were changed simultaneously, it will be necessary to conduct further tests and analyses to separate the effects of freeboard velocity and coal rank.

Summing the char product stream flow rates (drawoff from the reactor and the char separated from the product gas stream) and plotting the data as in Figure 5, we see that approximately 65% of the coal feed leaves the reactor as char product regardless of the freeboard velocity. However, the split in the two streams is indeed dependent on the freeboard velocity. In Figure 6, it has been shown that increasing the freeboard velocity will cause a relative decrease in the amount of char in the drawoff product stream. To distill these facts, increasing the reactor freeboard velocity appears to strip increased amounts of char from the bed leaving behind a larger mean particle.

With regard to the effect of the coals' caking and swelling properties on the char particle size, the data does not allow any strong conclusions. One would expect the higher free swelling coals to grow more during devolatilization. In addition, it has been proposed that as the coal goes through the sticky phase it is likely to gather a coating of fines on its surface. Looking at photomicrographs of char particle cross sections (see Figure 7), reveals the pore structure, but does not indicate any strong differences between comparable size char particles of different coals. In order to make a rigorous comparison of pore structure, one should look at the char product for identically sized coal. Because of the tenfold size spread in the coal feedstock, we cannot accomplish this from PDU char samples.

TABLE IV
Summary of Bed Material Particle Diameter Correlations

$\frac{D_p}{D_p}$ Bed Char vs. Coal	\dot{m} Coal Feed Rate	U_{fb} Freeboard Velocity	Coal Rank	Bed Temp.	Char Residence Time	\dot{m}/\dot{G}
\dot{m}	NF	Fair	Fair	NF	NF	NF
U_{fb}	NF	Strong	NF	NF	NF	NF
Rank	NF	NF	Fair	NF	NF	NF
Temperature	NF	NF	NF	NF	NF	NF
Residence Time	NF	NF	NF	NF	NF	NF
\dot{m}/\dot{G}	NF	Fair	Fair	NF	NF	NF

NF - No correlation found for the available data

\dot{G} - Total reactor inlet gas flow rate.

There appears to be a different wall structure on some of the Champion coal char particles (see arrow, Figure 7) which could be a result of the condensing and coking of the tars from this highly fluid coal or an accumulation of fines. At the time of this writing, it has not been determined if this wall structure difference is significant. This phenomena will be investigated further during future tests.

A question germane to fluidized bed operation and to particle cleaning requirements for the gas is how much attrition or growth of coal and char takes place in the bed. Figures 8 and 9 are plots of overhead product, bed product char and coal versus particle size. The bottom curves combine the two product chars into a "blended" product for comparison with the coal raw material. This presentation illustrates several facts:

- 1) Both particle growth and reduction take place in the devolatilization process as a result of inter-particle impact devolatilization, gasification, agglomeration and thermal expansion.
- 2) Both fines and oversize char fractions are produced from the mid-range coal particle sizes (note the bi-modal distribution of blended product).
- 3) Net production of -200 micron material is on the order of 10 percent of the coal feed (15 percent of char products).

CONCLUSION

The results of this study of char product characteristics along with the other results achieved during the past year of testing with the devolatilizer reactor indicate that the design concept for this portion of the process is feasible. Highly caking coals were processed for over two-hundred hours without pre-treatment utilizing the draft tube and recirculating fluidized bed concept. Char product produced in the process was adequately devolatilized and was in an acceptable size range, for both overhead and bed material fractions, to be used in the gasifier-agglomerator reactor. The attrition growth of particles which occurred was within acceptable limits with respect to overall process dynamics. To some extent, the resulting char particle size distribution depends on freeboard gas velocity, coal feed rate and coal rank.

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CONCEPTUAL LOW BTU COAL GASIFICATION COMBINED CYCLE PROCESS

FIGURE 1 -

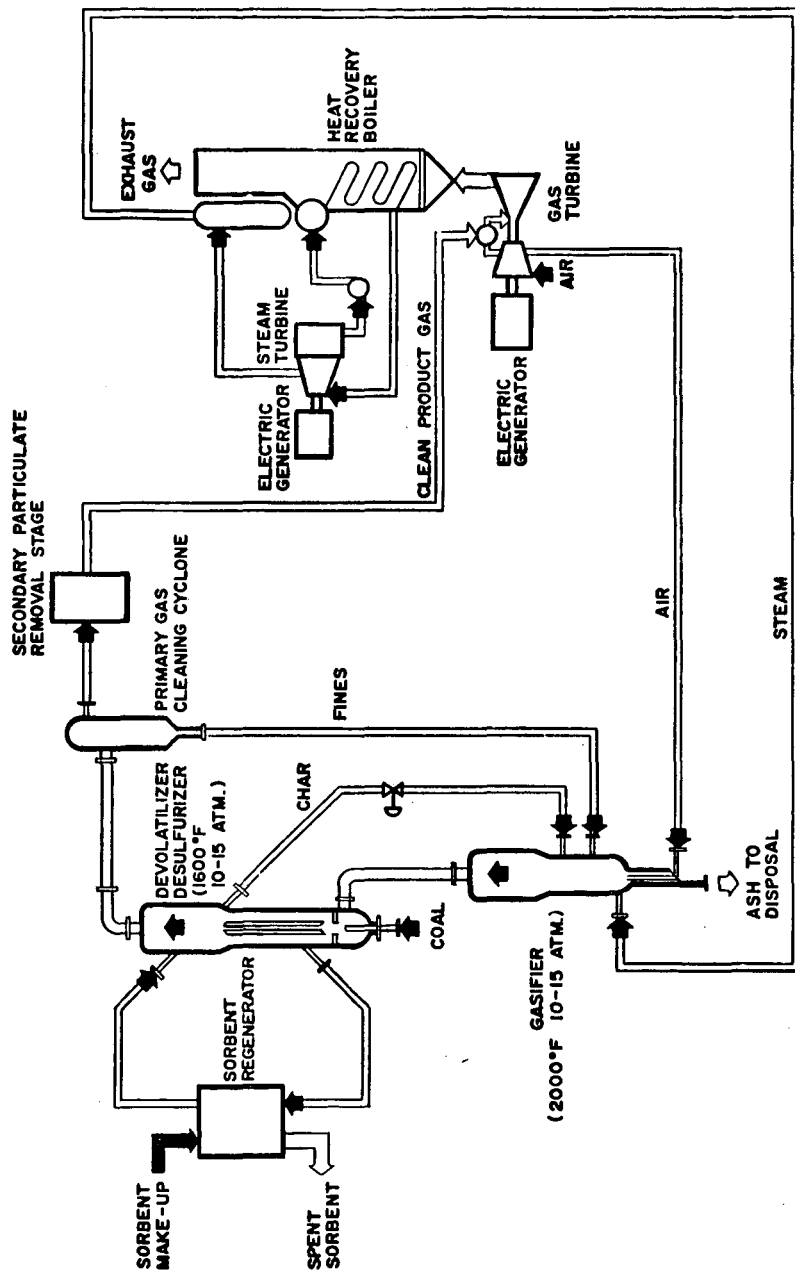


FIGURE 2 - BED PARTICLE SIZE VS REACTOR FREEBOARD VELOCITY

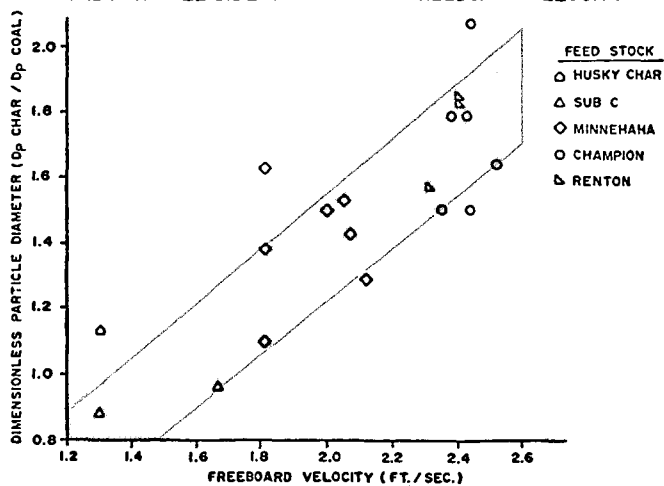


FIGURE 3 - BED PARTICLE SIZE FOR EACH FEEDSTOCK

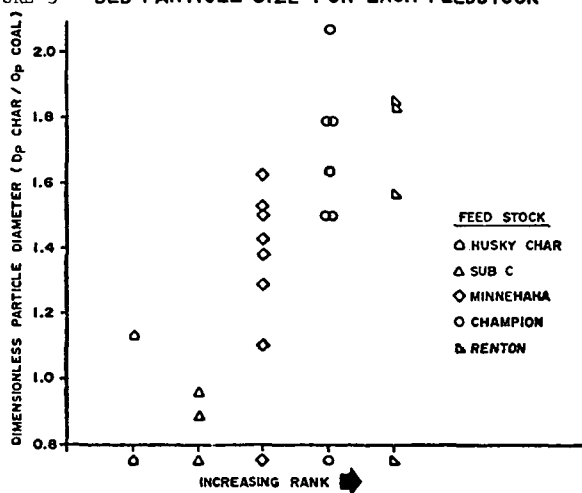


FIGURE 4 - BED PARTICLE SIZE VS LOADING

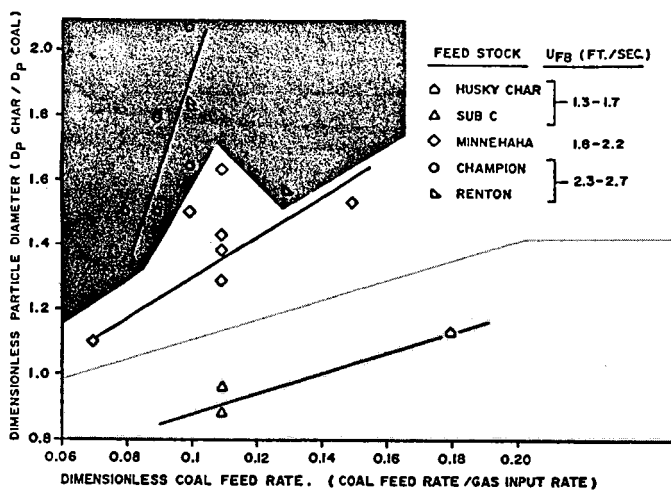


FIGURE 5 - TOTAL CHAR PRODUCTION VS FREEBOARD VELOCITY

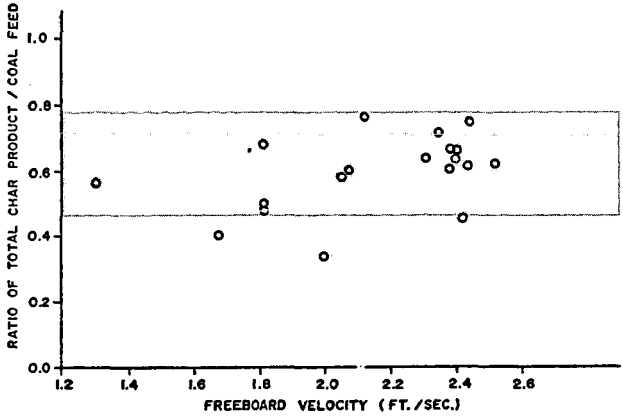
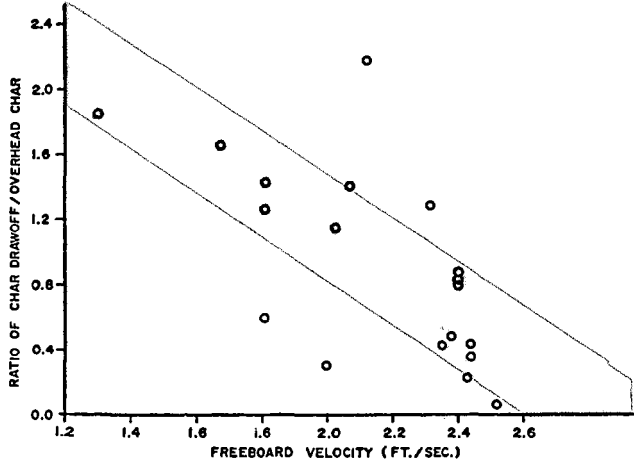
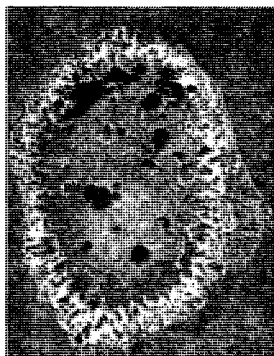


FIGURE 6 - AFFECT OF FREEBOARD VELOCITY ON CHAR STREAMS





Sub-Bituminous-C 30X



Minnehaha 30X



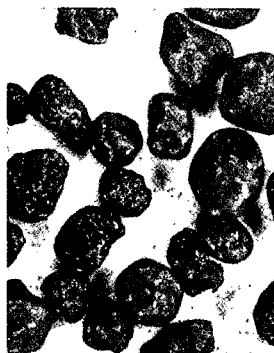
Champion 30X



Sub-Bituminous-C 10X



Minnehaha 10X



Champion 10X

FIGURE 7 - PHOTOMICROGRAPHS OF TYPICAL CHAR PRODUCTS

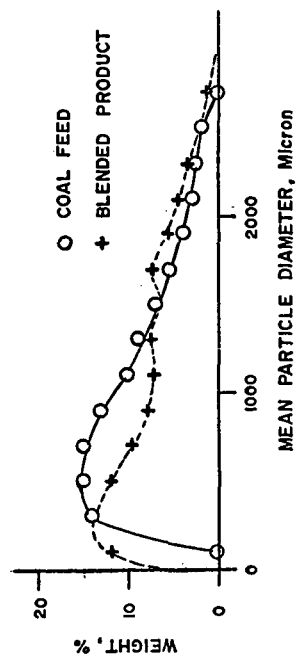
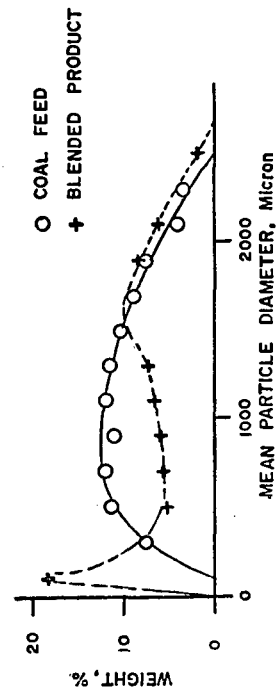
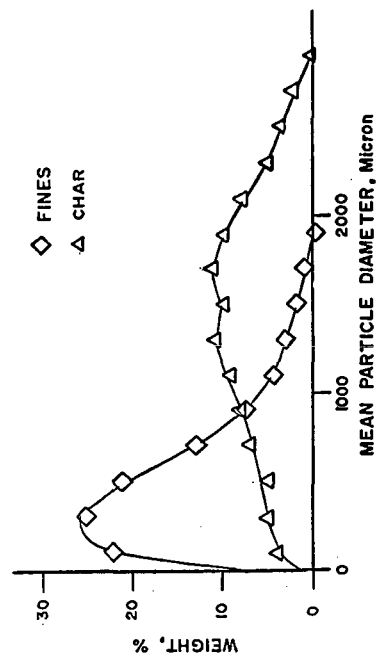
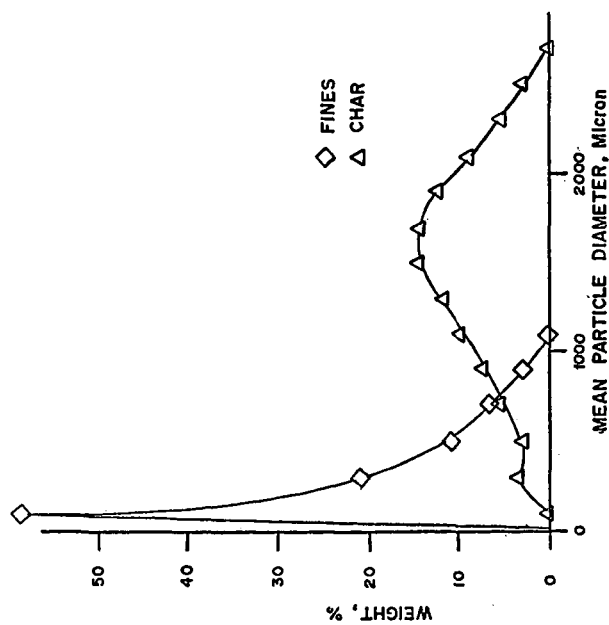


FIGURE 8 - PARTICLE SIZE DISTRIBUTIONS OF CHAR AND FINES PRODUCTS (MINNEHAHA COAL)
 FIGURE 9 - PARTICLE SIZE DISTRIBUTIONS OF CHAR AND FINES PRODUCTS (RENTON COAL)